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SOME RECENT OBSERVATIONS ON ACOUSTIC ATTRACTION OF PACIFIC REEF--ETC(U)

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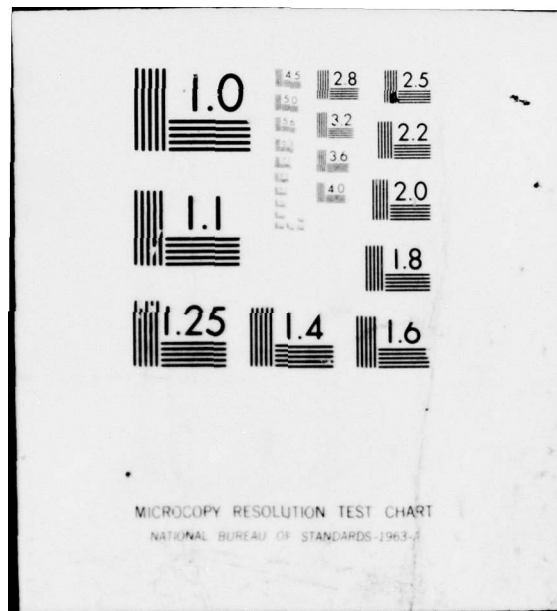
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CALIFORNIA STATE UNIVERSITY, LONG BEACH FOUNDATION

TECHNICAL REPORT NO. 11

December 1976

SOME RECENT OBSERVATIONS ON ACOUSTIC ATTRACTION OF
PACIFIC REEF SHARKS

by

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and

Richard H. Johnson

to

Office of Naval Research (Code 484)

Contract N00014-77-C-0113, NR-104-062

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Some recent observations on acoustic attraction of Pacific Reef sharks

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Received December, 1975

From October 1972 until January 1975 the authors conducted a shark-research expedition to French Polynesia, under sponsorship of the National Geographic Society and the U.S. Office of Naval Research. The study site was Rangiroa, the largest atoll in the Tuamotu Archipelago, located at Latitude 15° 00' S, Longitude 147° 40' W, approximately 300 km northeast of Tahiti. The expedition's objective was field research on the comparative behavior of the reef sharks of the area, primarily emphasizing social interactions and diel patterns of activity and movement. In addition to findings in the above primary areas (to be published elsewhere), one sound-playback experiment was conducted, and a number of miscellaneous responses to sound were noted. These acoustic observations, with comments upon them, are presented in this paper.

The existing literature on acoustic behavior of sharks is discussed in this symposium volume by Myrberg *et al.* (1976). Previous sound-playback experiments at Rangiroa were conducted in 1968 by Brown (1973) and in 1969 by Nelson and Johnson (1970). The acoustic playback study of Nelson and Johnson (1972) at Eniwetok (now Enewetak), Marshall Islands, also involved species and conditions similar to those of the present study.

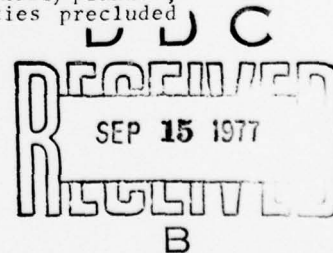
The reef species in which acoustic responses were noted were: the gray reef shark, *Carcharhinus amblyrhynchos*; the blacktip reef shark, *C. melanopterus*; the silvertip shark, *C. albimarginatus*; and the reef whitetip shark, *Triaenodon obesus* (Fig. 1). One pelagic species, the oceanic whitetip shark, *C. longimanus*, was also observed during acoustic playback.

RESPONSES TO PLAYBACK OF TEST SOUNDS

One controlled sound-playback experiment was conducted^x which tested the attractiveness to sharks of the following three low-frequency, pulsed signals of differing waveform: (1) 50 Hz sine wave, (2) 50 Hz square wave, and (3) 25-100 Hz band of filtered noise. All three sounds had a pulse rate of 10/sec, i.e., were sinusoidally amplitude modulated at 10 Hz, and were presented as intermittent trains of pulses using the sequence described in Nelson and Johnson (1972). The acoustic apparatus, playback

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^x Several additional playback experiments were originally planned, using different test sounds, but other priorities precluded these.



technique, and experimental design also generally followed that of Nelson and Johnson (1972). The test sounds were played into the water at a level of 56 dB re: 1 μ bar at 1 m, using a Uher 4000 Report-L tape recorder, an Altec 1594-A amplifier, and a U.S. Navy J9 transducer (speaker).

Playback on the ocean reef

Sounds were played back at nine sites more or less evenly spaced along the ocean reef from about 7 km east of Avatoru Pass to about 3 km west of Avatoru Pass. The speaker was suspended about 15 m below the anchored boat (a 5-m Avon inflatable) and observations made by a diver in the water at the surface. At each site, one test sound per day was presented, and the three sounds were sequenced among the nine sites in a manner which evenly distributed the effects of interdaily habituation, thus preventing this from biasing the comparisons between the test sounds.

A total of 27 observations periods were conducted, each consisting of a 10-min *control period* (speaker submerged, sound off), and a 10-min *test period* (5-min sound on, followed by 5-min sound off). The 5 minutes of post-sound observation was included because previous studies had shown that approaching sharks often do not arrive in the vicinity of the speaker until sometime after the sound has ended (Nelson and Johnson, 1972).

Table 1. Numbers of sharks sighted during playback of three low-frequency, pulsed sounds of differing waveform. Based on 9 test periods and 9 control periods for each sound.

	Sound 1 (50 Hz sine wave)	Sound 2 (50 Hz square wave)	Sound 3 (25-100 Hz noise)
Number of sharks			
Test (sound)	3	1	13
Control	2	3	2

The numerical results are given in Table 1. The two main species attracted were the silvertip shark (6 sightings, seen only during or after Sound 3) and the gray reef shark (5 sightings). One oceanic whitetip shark was sighted just after Sound 3, apparently attracted from the open ocean beyond the reef.

From the numbers of sharks sighted, it is clear that only Sound 3 could be considered attractive. Furthermore, only Sound 3 resulted in obvious acoustic attractions, judged from swimming speed, orientation, and closeness of approach, e.g., a direct, high-speed approach to within 1 m of the speaker.

These results are not entirely as expected. In comparison to previous playback studies, they are in agreement in regard to Sound 1 (expected to be unattractive) and Sound 3 (expected to be attractive). With regard to Sound 2, however, the lack of response is interesting in view of the findings of Myrberg *et al.* (1969) that irregularly pulsed 55 Hz "overdriven sine waves" (essentially square waves) were highly attractive to Baha-

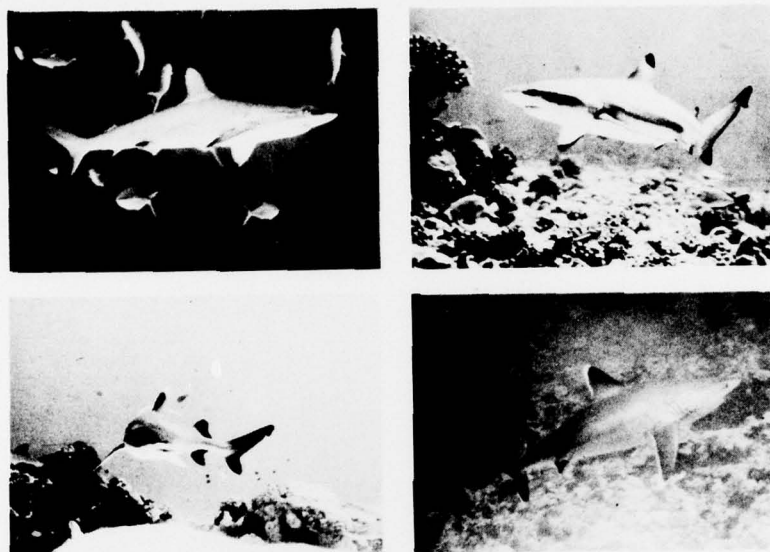


Fig. 1. Some acoustically responsive reef sharks of Rangiroa, French Polynesia. Upper left, gray reef shark. Upper right, blacktip reef shark. Lower left, reef whitetip shark (with attached tag). Lower right, silvertip shark. Photos by R. Johnson.

mian sharpnose sharks, *Rhinoprionodon porosus*. At present we can only speculate about the reasons for this difference. Perhaps the two sounds were not as similar as supposed (further analysis may determine this), or perhaps the species differed in their acoustic preferences. In addition, motivational factors may have been significantly different between the two experiments, e.g., social facilitation appeared to have increased the response intensity of the sharpnose sharks, which occurred in groups in the playback area.

Playback in the lagoon

After completion of the ocean-reef experiment, some playbacks were conducted at Mahuta - a rich, coral-reef area at the lagoon end of Avatoru Pass. Unlike the ocean-reef sites, Mahuta was subject to much spearfishing activity; usually several boatloads of local divers operated there daily at the slack tides. Therefore the sharks of this area were quite accustomed to human activity, feeding regularly on the wounded fish which frequently broke off the fisherman's spears. In addition, expedition personnel regularly spearfished and baited at Mahuta to attract reef whitetip and gray reef sharks for underwater tagging studies.

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Previously at Mahuta, the authors had seen many instances of strong acoustic attraction of sharks to speared fish (see descriptions below). It seemed likely that playback at this site would bring the "dramatic" attractions desired for cinematography. In addition it would provide a good further test of the sound previously found unattractive. It was felt that, if sharks were ever to respond to any particular sound, it would be at Mahuta.

The results were very surprising. The sharks made no discernable responses to either Sound 1 or to the normally attractive Sound 3. On arrival at the site, Sound 1 was played first, resulting in no apparent response from four whitetips swimming slowly through the area. Sound 3 was then played, and again no apparent responses were seen, this time from three whitetips observed. It was confirmed that the speaker was operating properly. During control periods for both playbacks several whitetip and gray reef sharks were seen. Sound 3 was later repeated, again with no response. Sound 2 was not tried.

These results are puzzling in view of the results of previous sound playbacks at Mahuta, i.e. Brown's 1968 observations of highly excited responses from whitetip and gray reef sharks, and the author's 1969 observations of definite, though less intense, attraction of whitetips. Why then did similar responses not occur during the present Mahuta playbacks? Again, only speculation is possible, but perhaps the Mahuta sharks had become so conditioned to human-related feeding, that their "normal" acoustic preferences had become altered. Perhaps these sharks differed from those of other areas in the timing of their feeding, having periods of low motivation (related to satiation) resulting in a non-responsiveness to sounds. There was no evidence, however, that the Mahuta sharks had fed heavily just prior to the present playbacks.

One general conclusion that can be drawn is that even acoustically responsive species of sharks *do not always* respond to attractive sounds, even where habituation to the sounds themselves is not a factor.

RESPONSES TO OTHER SOUNDS

Speared, struggling fish

The attraction of sharks to the struggling sounds of speared fish is well known (Nelson, 1969; Nelson *et al.*, 1969) and many such instances were observed during the present expedition. The following is a typical example from the field notes:

"Baiting and tagging at Mahuta, depth 10 m, visibility about 30 m. No sharks in view. Near the bottom, a 3 kg grouper is speared. The fish struggles (vibrates) vigorously against the spear and dashes rapidly into a coral cave, struggling intermittently thereafter. Within 5 sec of the spearing, three whitetip sharks appear at the limit of visibility, approaching from three different directions. They are moving at moderately high speed, and are oriented directly towards the spearing site. Within 30 sec, five whitetips are at the site, excitedly circling the cave containing the wounded fish."

While all the species of sharks that were attracted appeared well oriented to the source of the sounds, behavioral differences were evident when the sharks arrived at the spearing site. Gray

reef sharks usually approached rapidly, and were very adept at quickly seizing exposed prey. They would attack a fish on a spear at any level in the water column, from the bottom to very near the surface, but would not swim very far into the coral to secure prey. The reef whitetip sharks, in contrast, were reluctant to pursue prey much above the bottom, but showed no hesitation in entering deeply into coral caves and crevices to secure wounded fish that had taken refuge there.

In general, the struggling sounds of relatively large fish, e.g. 10 - 20 kg grouper, evoked more intense attraction responses than the sounds of smaller speared fish, e.g. 1 kg surgeonfish: even where both appeared audible to the sharks. Perhaps the acoustic characteristics of the large fish sounds (intensity, frequency, pulse rate) were recognized by the sharks as indicative of an unusually good feeding opportunity. Also, the sharks might have habituated to the more frequently occurring sounds. At Mahuta, large groupers were only rarely speared, as they were considered unsuitable as food because of a high risk of ciguatera poisoning. During spearfishing at Mahuta, after many small surgeonfish had been taken, the response of sharks to each spearing could wane considerably; yet if a large grouper was then speared, relatively intense attraction might then occur.

The intensity of attraction to speared fish also appeared to be related to the length of time since spearfishing last occurred. At Mahuta, particularly vigorous responses were most likely when spearfishermen returned after some days or weeks, their absence perhaps being due to bad weather. Increased feeding motivation was probably at least partly responsible for this.

Hooked, struggling fish

Attraction to a hooked fish was observed when a 1 kg snapper was accidentally hooked while "underwater angling" for small gray reef sharks (length, 0.75 m) with baited hook and hand line. On this occasion a mixed group of snappers and sharks had gathered. When the fish was hooked and began struggling against the line, the sharks immediately accelerated in to attack. Although the struggling sounds were suspected of releasing this behavior, visual cues could have played a role at such short distances (5 - 10 m), especially in directing the final approach to attack. The response to the hooked fish did not appear substantially different from the many responses to speared fish noted on other occasions from these small sharks.

Struggling fish - in the mouth of a predator

The following observation is significant because it gives insight into one possible value of acoustic attraction to sharks under conditions of natural predation, i.e., without the human influence of spear or hook-and-line fishing. From the field notes: "Observing local divers spearfishing at Mahuta for yellow surgeonfish, *Acanthurus xanthopterus*. High slack tide, visibility 40 m, water depth 10 - 15 m. Many surgeonfish already captured, several others had broken off spears and taken refuge in the coral. Several reef whitetip sharks in the area searching for wounded fish. One whitetip circles in towards a 1.5 kg surgeonfish, apparently wounded and bleeding, lying quietly on an open patch of sand. When the shark's snout contacts it, the fish "revives" and swims away upwards.

The shark pursues the free-swimming fish closely, making 2 or 3 passes at it, eventually seizing it. Upon being seized, the fish struggles (vibrates) actively in the shark's jaws. Immediately after the fish starts struggling, six other white-tips (which had been slowly circling nearby) rapidly accelerate towards the shark holding the fish. The sharks engage in a brief, frenzied "fight" over the fish, excitedly chasing the first shark to a nearby coral patch where this shark (still holding the fish) appears to take refuge in a cave. The level of excitement exhibited by the sharks during this incident was equal to the greatest ever observed for this species. There is obvious adaptive value in one shark being able to localize immediately another shark that has successfully captured large prey, i.e., prey too large to be swallowed quickly in one piece. This second shark might succeed in taking the prey away from the first shark, or at least might be able to share in the remains after the first bite has been removed.

Sounds of feeding sharks

As first proposed by Banner (1968, 1972), it is generally accepted that various sounds associated with active predation, e.g., the hydrodynamic/acceleration sounds of actively feeding fish, can be utilized by sharks in detecting and locating prey. One particular sound associated with the feeding of sharks on large prey might be of considerable significance - the rapid body vibrations produced when "sawing out" a bite-sized piece. These actions appear most intense in the faster-swimming, stiffer-bodied species such as the gray reef shark. Many instances of this were observed on Rangiroa, and although no acoustic recordings were obtained, it seemed that these actions would generate the kinds of sounds known to be attractive to sharks. These body vibrations during feeding may, in fact, be rather similar to the body vibrations during struggling, e.g., of a speared fish. To the observer, both appear to constitute a "maximum vibratory effort" by the fish, i.e., the maximum intensity and highest frequency that the body musculature is capable of producing.

Fish vocalizations

One incident was observed in which a shark apparently responded to the vocal sounds of a wounded soldierfish, *Myripristis* sp. The small fish was speared under a coral ledge at a depth of about 10 m on the ocean reef. The free diver then pushed off the bottom and began swimming back to the surface, holding the impaled fish on the end of his spear. At this time a gray reef shark, which has arrived some minutes before, was passing by about 12 m away. The soldierfish then emitted a 2-sec series of grunts, plainly audible to the diver. Immediately after the onset of this sound, the shark abruptly turned and accelerated directly towards the sound source. It turned away about 5 m from the diver.

In one previous study, two fish calls (from the catfish, *Galeichthys felis*) were among the recorded sounds shown to be attractive to young lemon sharks (Banner, 1972). Like the soldierfish sound, both catfish sounds consisted of "several closely spaced pulses", a characteristic that Banner regarded as significant in their attractiveness.

Sounds vs odors

The following observation is interesting because it involved a 2-choice stimulus situation where a shark moved *away* from an odor source to move *towards* a sound source. The incident occurred at Mahuta, while underwater angling for whitetip sharks with hand-line and baited hook. From the field notes:

"R. Johnson spearfishing for bait, D. Nelson handling the fishing line. Baited hook lying on a sandy patch at 15-m depth. One whitetip circling the bait (piece of moray eel) with moderate interest but has not yet taken the bait. Visibility dropping to less than 15 m, necessitating D. Nelson repeatedly free-diving to about a 5-m depth in order to see the bottom clearly. At a distance of about 30-40 m from the bait (well beyond limit of visibility), R. Johnson spears a fish. While submerged, D. Nelson hears the speargun discharge, followed by a burst of struggling sounds. Within one second of the onset of the sound, the circling whitetip suddenly turns and accelerates away in the direction of the speared fish. Upon surfacing, R. Johnson reports that two excited whitetip sharks had arrived at the spearing site within several seconds of the spear discharge.

In the above incident, at the moment of the response, the attractive value of the struggling sound was clearly higher than the attractive value of the bait odor. This is not surprising considering the modes of action of the two stimuli - each potentially indicative of a feeding opportunity. Sounds normally represent feeding opportunities requiring immediate, high-speed response - a delay of even a few seconds could mean a great advantage lost, e.g., a struggling fish reaching shelter. Sounds are also very transient stimuli; when source emission ends, opportunity for orientation to the source ends. Odors, however, travel slowly, and therefore usually represent feeding opportunities that are *already somewhat old*. There is less response urgency, as the wounded prey has probably already reached shelter, if capable of doing so. The extra expenditure of energy for a maximum speed approach would be less warranted, unless competing sharks are present. Furthermore, chemical stimuli persist much longer; once formed, an odor corridor does not disappear instantly.

Conditioned responses to speargun sounds

Reports from the local spearfishermen of Rangiroa indicated that, in certain heavily fished areas such as Mahuta, the discharge sound of the Tahitian, rubber-powered, arbalète-type speargun is sufficient to attract sharks - even though no struggling sounds may occur (C. Tokoragi, pers. comm.). The experiences of the authors confirmed this, i.e., that missed shots often still resulted in sharks (primarily whitetips) swimming directly in to the site of the speargun discharge. These approaches were rather mild, however, compared to those elicited by actual struggling fish.

Banner (1972) reported that sounds consisting of only a single pulse were generally unattractive to young lemon sharks. The speargun sound is essentially a single-pulse sound, and would therefore not be expected to elicit unconditioned attractions. Neither would the momentary "thump" acceleration sound of a fish darting away after being narrowly missed by a spear. Unlike the various repetitively pulsed sounds which are attractive to sharks, a single-

pulse sound may be interpreted as a fish which has escaped harm and is therefore a relatively poor candidate for a meal. It seems likely, therefore, that the shark attractions to speargun sounds were conditioned responses, based on the association of these sounds with the special feeding opportunities that they usually represented.

CONCLUSIONS

The observations discussed in this paper, while primarily incidental in nature, do tend to confirm the importance of acoustic stimuli in the feeding behavior of Pacific reef sharks. This is not to suggest, however, that the sense of hearing in sharks is significant only in regard to the locating of food. Other possible uses might include: (1) detecting and escaping from potential dangers, e.g., predators, various human activities, (2) detecting and locating other individuals for the purpose of social/agonistic interaction, and (3) detecting acoustic features of the environment for the purpose of geographical orientation, e.g., locating the relatively "noisy" reef or shoreline from the quieter offshore waters - as suggested by Sciarrotta (1974).

ACKNOWLEDGEMENTS

The authors are primarily grateful to the National Geographic Society for sponsoring the expedition from which this paper resulted. Special thanks are due all the expedition participants, especially W. Smith and V. Nelson who helped with the acoustic playbacks. Thanks are also extended to those in the government of French Polynesia who cooperated in the logistical aspects of the expedition, particularly C. Tokoragi, Service de la Pêche, Rangiroa. The authors also acknowledge the U.S. Office of Naval Research for support, through contract N00014-68-C-0318, under project NR-104-062, of the program of shark research of which this study is a part.

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DISCUSSION OF ORIGINAL LECTURE OF D.R. NELSON

C.J. Chapman: Obviously you attracted teleosts as well as sharks. Did the teleosts show the same sort of behaviour and directly move to the sound source?

D.R. Nelson: Not in quite the same manner. They did not appear to exhibit the rapid, straight-in approach typical of the sharks. Instead they gradually gathered in the vicinity of the speaker, probably coming in by more circuitous routes down among the coral. Especially with the smaller groupers, we were sometimes not aware of them until they were quite near - perhaps some of them had simply come out of the coral caves near the speaker. Groupers usually remained at or near their point of closest approach, usually hovering just off the bottom facing the transducer. This often resulted in a distinct upward inclination of the body axis - a posture we called "tail-standing". Whether this orientation indicated true sound localization could not be determined, of course, because the speaker (a "novel" object in their environment) suspended a few m above the bottom was in plain sight.

C.J. Chapman: Do sharks normally feed on healthy fish? You said they were attracted to wounded fish, but do they feed on healthy fish and do they orient to the swimming sounds of these fish?

D.R. Nelson: Although I know of no specific data on this, it seems that there are not enough wounded or unhealthy fish to support typical populations of sharks. I personally believe that most sharks routinely feed on healthy prey - and not always very large prey either. Sharks, however, have developed sensory systems to detect and take immediate advantage of prey individuals in distress - and most of the sounds used in playback studies to date have resembled distress sounds (i.e., struggling sounds) rather than normal swimming sounds. Sharks also respond to the sounds of sudden turns and accelerations, such as during excited or frenzied feeding of predatory species, or of the "stamping" of frightened schools of fish. I do not know if sharks can detect or orient to the normal sounds of unexcitedly swimming fish. I know of no data on this.

C.J. Chapman: Finally, did you say that it didn't matter how loud the sound was played back, that they still were attracted? And did sound level affect how close they moved in to the speaker?

D.R. Nelson: What I said was that I know of no instance where playback level was so high that approaching sharks were unwilling to complete their approach right up to the speaker. We did not, however, study specifically the effect of playback amplitude on acoustic attraction. The sound level we played back at Rangiroa in 1972, and at Eniwetok in 1971, was about 56 dB re: 1 uhar at 1 m (broadband measurement), a rather high level, I suspect,

compared to some naturally occurring sounds. Yet many of these sharks would come all the way in, some even striking or biting the speaker. We did also observe a few momentary startle responses (sudden darts away from the speaker) very near the speaker - I think these occurred when, by chance, an approaching shark happened to cover the last 10 m or so of its approach during a momentary quiet period (an interval between pulse trains), then was very near the speaker when playback resumed. These were very momentary responses with the shark quickly resuming interest in the speaker.

S. Dijkgraaf: This morning in the film playback of struggling sounds the sharks came straight to the speaker and one even caught it. It is quite clear that there was an acoustic attraction in these sharks, but to what extent was the location of the speaker purely acoustically determined, or could vision have played a role? How could you separate these influences?

D.R. Nelson: We are not certain whether (or at what distance) vision is involved because we don't know enough about their visual acuity. In playbacks where the speaker is suspended in plain sight I would make just a guess that vision is used by the approaching shark within perhaps the final 10 m. Certainly not more than about 20 m, may be much closer.

F.J. Verheijen: Did you ever use a dummy speaker or second speaker? Then you might see something about the role of vision.

D.R. Nelson: We didn't have an opportunity to set up a dummy speaker in our experiments. However the Australian researcher Theo Brown has performed playback experiments at Rangiroa in which the speaker was hidden down under the coral formations. The sharks were still able to locate the exact source of the sounds. In fact he reports one instance where several reef whitetip sharks, *Triacnodon obesus*, became stuck in the entrance of a coral cave after jamming themselves in trying to get at the speaker inside.

F.J. Verheijen: I wonder about the effect of pulse rate because you suggested the best was 20 pulses per second. This seems to me rather frequent for fish tail movements.

D.R. Nelson: The only experiment thus far specifically investigating pulse rate was Myrbergs *et al.* (1972) study in which they compared the attractiveness of 1, 5, 10, and 20 pulses per second, and found the 20 per sec. signal most attractive. I agree with you that this rate seems high for a natural struggling sound - perhaps it represents some kind of supernormal stimulus, but this is only conjecture. In our playback experiments (Nelson and Johnson, 1972) at Eniwetok we did not test pulse rate *per se*, instead we tested pulse-train intermittency, and constant versus varying pulse rate. The most important factor appeared to be intermittency.

F.J. Verheijen: What would happen if your sound source was not stationary but actually moving around?

D.R. Nelson: I suspect that the sharks would be attracted just as well. In fact, some of our playbacks were with a slowly moving source - the speaker suspended from a drifting boat.

J.A.R.A.M. van Hooff: Did you analyze the properties of the sounds coming from speared fish? Are they characteristic in some way which might be correlated with the properties of your most attractive artificial sound?

D.R. Nelson: Yes, they are correlated in that they are predominantly low frequency and they are pulsed.

J.A.R.A.M. van Hooff: What would be a normal pulse frequency for a speared fish?

D.R. Nelson: That certainly depends on the fish's size and its species. You would expect that the larger fish, the lower the struggling pulse rate. Although we have nowhere near as much data as we would like, our recordings of speared fish ranged in pulse rate from about 5-10/sec to 12-14/sec, while a stampeded fish sound appeared to have a more irregular rate of 7-30/sec. (Nelson and Johnson, 1970)

R.W. Piddington: What is the amplitude of displacement of the J9 speaker relative to the amplitude of tail beats of a wounded fish? I would suspect that you are getting a relatively bigger pressure component and smaller nearfield with the speaker.

D.R. Nelson: We have never made such measurements, but I would tend to agree with you. Remember, of course, that most of the sharks appeared to be attracted from out in the far field.

R.W. Piddington: Do you have any idea of the amplitude at the point where the shark makes the detection, or any ideas about the mechanism by which it makes the angle discrimination; for instance is it with pressure or displacement?

D.R. Nelson: I can give you only a rough estimate, since we don't have enough data on the distances from which the sharks are attracted. All we know is that it is at least 200 m over depths of 10-15 m, and at least 400 m over deep ocean. Based on simple far-field calculations, the displacements at these distances might be at least five or ten Angstroms - but this calculation is subject to much error from the uncertainties of spreading mode (spherical or non-spherical), and effects of the near surface and bottom.

P. Görner: Does the angle between the axis of the sound projector and the location of the shark have any effect on attraction?

D.R. Nelson: In the far field I would think not (as all displacements are radial), except as it affects the sound amplitude. In the near field, it might, but unfortunately I have no data on this because it did not occur to me years ago when I was measuring directional responses in trained lemon sharks in a 12-foot pool. During those experiments I always had the speaker axis aimed directly at the point at which the shark was asked to make a directional response. Thus the responses always occurred in the axis of the J9 speaker. I am sorry now that I didn't try some other speaker orientations. I have the feeling that the shark would still have made the correct choice, but this is just an opinion and needs to be confirmed.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 11	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 1417K-111
4. TITLE (and Subtitle) Some recent observations on acoustic attraction of Pacific reef sharks		5. TYPE OF REPORT & PERIOD COVERED Technical Report Oct 72- Jan 75
7. AUTHOR(s) Donald R. Nelson and Richard H. Johnson		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS California State University, Long Beach Foundation, Long Beach, California 90840		8. CONTRACT OR GRANT NUMBER(s) N00014-77-C-0113
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research, Oceanic Biology Program, Code 484, N.O.R.D.A., N.S.T.L., Bay St. Louis, Miss. 39520		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR-104-062
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE December 1976
		13. NUMBER OF PAGES 11
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release; Distribution Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES 405 797		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Bioacoustics Shark behavior		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Responses of Pacific reef sharks to acoustic stimuli were observed at various times during a shark-research expedition to French Polynesia, conducted between October 1972 and January 1975. The results of one controlled sound-playback experiment and a number of miscellaneous observations are discussed. Reef species exhibiting responses were: the gray reef shark, <u>Carcharhinus</u> (in a controlled sound playback experiment)		

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amblyrhynchos; the blacktip reef shark, C. melanopterus; the silvertip shark, C. albimarginatus; and the reef whitetip shark, Triaenodon obesus. One pelagic shark, the oceanic whitetip, C. longimanus, was seen during acoustic playback.

The playback experiment involved the following three test sounds (of 10/sec pulse rate): (1) 50 Hz sine wave, (2) 50 Hz square wave, and (3) 25-100 Hz band of noise. Only Sound 3 resulted in clear attractions, based on numbers of sharks sighted and their behaviors. At other times throughout the expedition, attraction responses were observed to the following types of sounds: (1) speared, struggling fish; (2) hooked, struggling fish; (3) struggling fish - in the mouth of a predator; (4) fish vocalizations; and (5) speargun-discharge sounds -- the latter being a conditioned response observed at a site where native spearfishermen operate daily.

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